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EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

FINAL REPORT
VOLUME 1
EXECUTIVE SUMMARY

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July 1980

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FOREWORD

The Extravehicular Crewman Work System is a study of manned extravehicular activity for performing construction and satellite servicing in Earth orbit.

This report is divided into four volumes:

Volume 1	Executive Summary
Volume 2	Construction
Volume 3	Satellite Service
Volume 4	Program Evolution

Volume 1, Executive Summary, presents an overview of work reported in Volumes 2, 3 and 4.

This study program has been performed under contract by Hamilton Standard for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center over a period from April 1977 to June 1980.

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EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 1, Executive Summary

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ABSTRACT

The Extravehicular Crewman Work System (ECWS) study program defines requirements for manned EVA support of space construction and satellite service projected for the 1980's. The study starts with identifying characteristics of structures and satellites, which leads to defining requirements for EVA tasks and support equipment. Next, equipment concepts are presented and evaluated for extravehicular life support, spacesuit and work aids. The study includes preliminary design of recommended ECWS equipment concepts and identifies new technology developments required for their implementation.

The study concludes with a recommended sequence for evolving from present Shuttle EVA capability into projected EVA construction and satellite service support capability. This sequence parallels NASA projections for development and use of Space Transportation System capabilities.

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INTRODUCTION

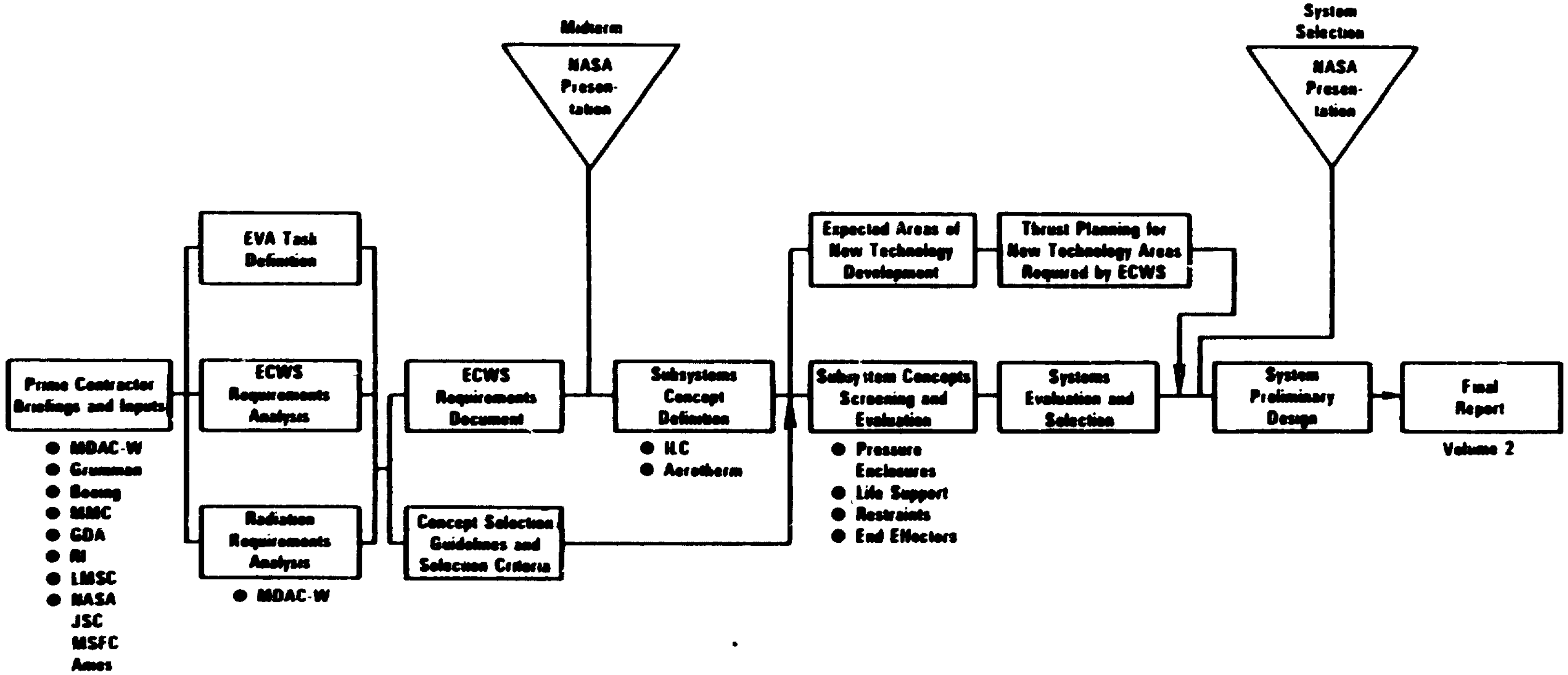
Starting with this decade and continuing out through the end of the twentieth century NASA plans to use the Space Transportation System (STS) to launch and service satellites and place large structures in Earth orbit. Extravehicular activity (EVA) will play a major role in construction and satellite service operations. The Extravehicular Crewman Work System (ECWS) Study Program examines construction and satellite service operations and defines EVA equipment concepts to support these operations in the 1980 to 1990 period.

Objectives of the ECWS Study Program are:

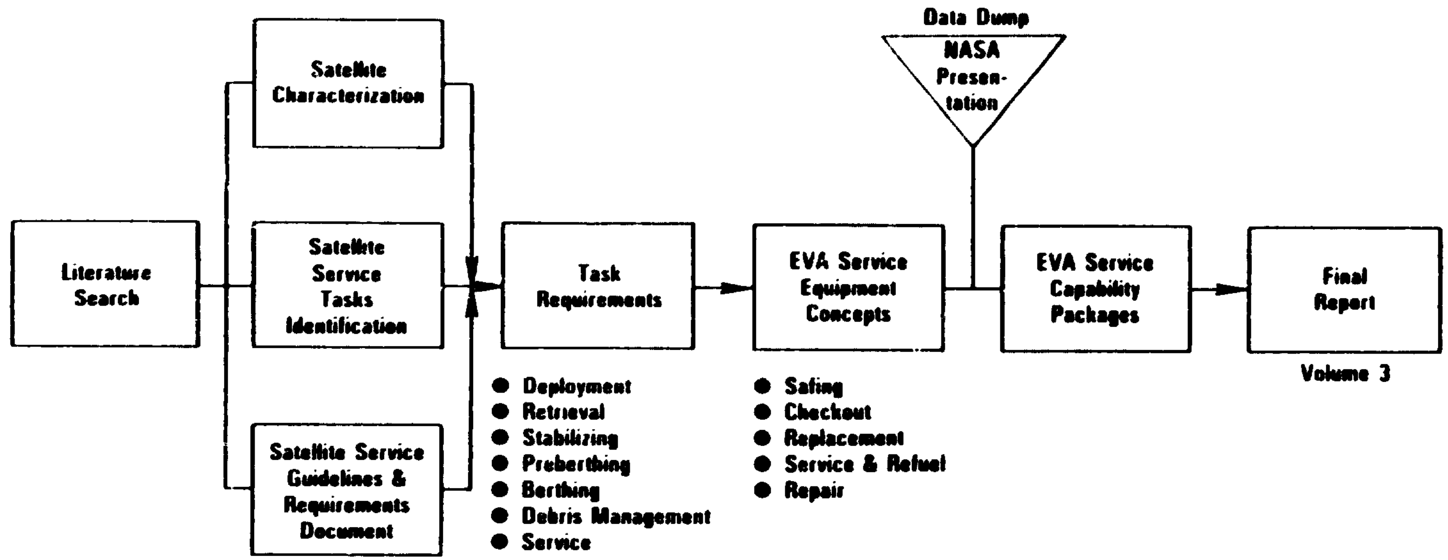
- Construction (Volume 2)
  - Identify extravehicular crewmember work task requirements.
  - Define system performance requirements and concept selection criteria.
  - Identify and evaluate alternate configuration concepts.
  - Analyze the selected concept configuration.
- Satellite Service (Volume 3)
  - Identify potential EVA service tasks of the projected satellite population.
  - Identify and analyze EVA worksite equipment concepts to support satellite service.
  - Define the impact of satellite service requirements on the ECWS concept.
- Program Evolution (Volume 4)
  - Identify the technology development status of ECWS candidate concepts.
  - Identify technology development requirements of selected ECWS concepts.
  - Prepare technology thrust planning data and schedules for phasing ECWS concepts into the on-going STS program.

Logic flows for the three study volumes are shown in the accompanying diagrams.

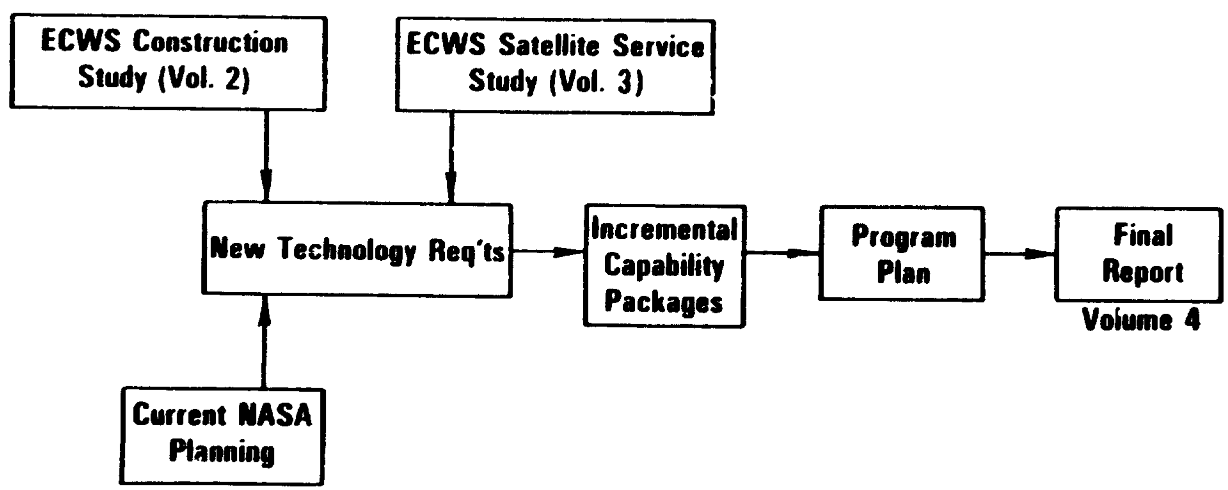
ECWS CONSTRUCTION STUDY FLOW



ECWS SATELLITE SERVICE STUDY FLOW



ECWS PROGRAM EVOLUTION STUDY FLOW



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SPACE PLATFORM CAPABILITY EVOLUTION

NASA-sponsored studies of space station, space platform, space operations center, space structures and space construction published since 1977 point toward establishing long term, manned capability in space during the 1980's.

The following excerpt from NASA's Office of Space Transportation FY'81 Activities Plan (draft) shows the macroscopic steps currently being planned to develop this capability.

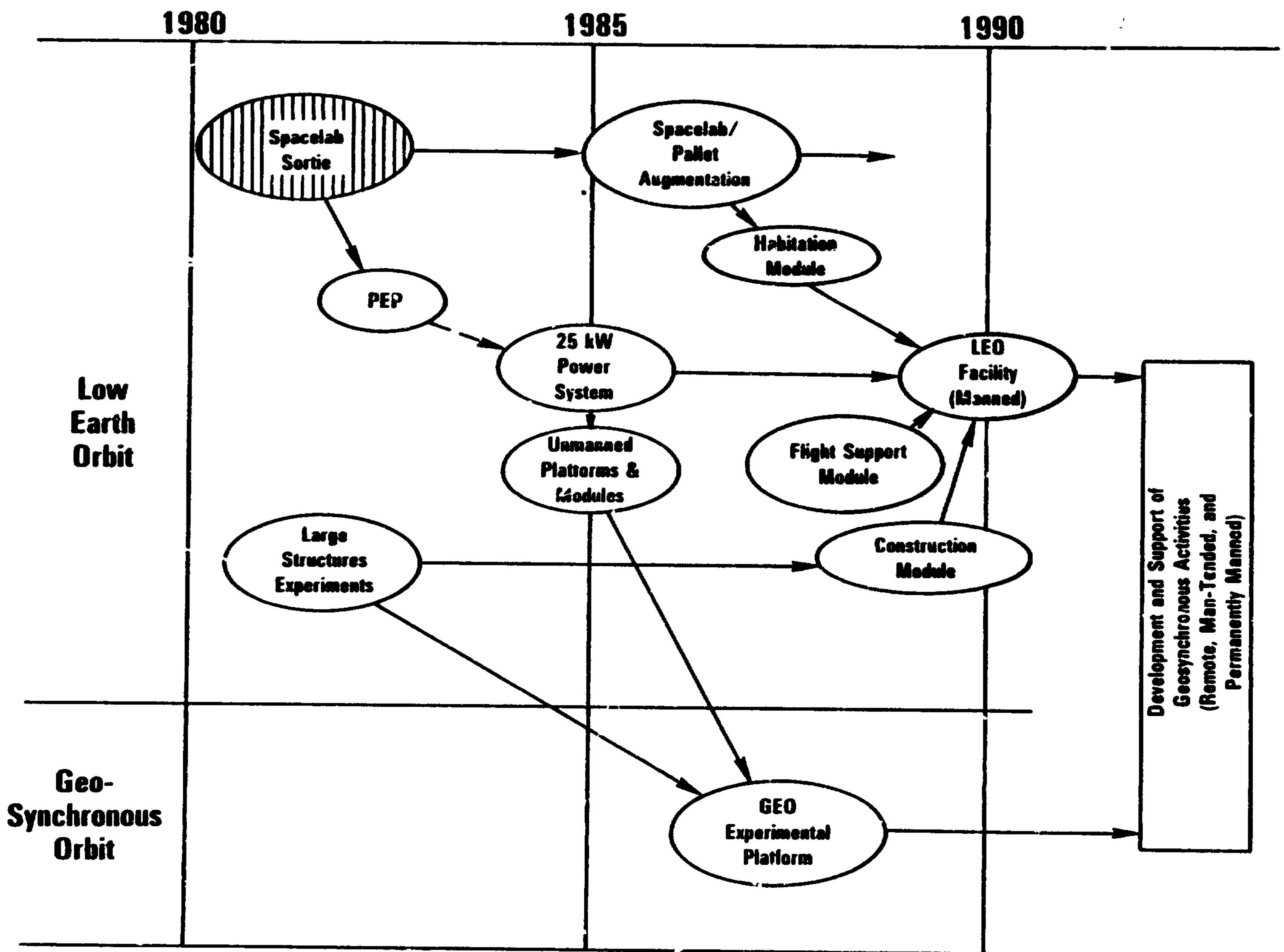
"Space Platforms

The Shuttle is a platform with a nominal stay time in space of 7 days, too short a time for maximum benefit to some experiments. The initial improvement in platform capability will be to equip the Shuttle with the Power Extension Package, which will increase that stay-time to 12 to 20 days depending upon orbit inclination. With the advent of the 25KW Power System, the on-orbit stay of the Orbiter can increase the maximum and provide a contamination-free environment through the Power System attitude control. With the Power System/Orbiter capability in the Sortie mode as a basis, the natural evolution is for yet longer orbit stay-times for payloads. The Power System in a free flyer mode will provide for a direct transition of Sortie pallets and payloads to the Power System with minimal modification and integration. With instruments and/or pallet-mounted payloads being attached directly to the Power System, the free-flying platform system is capable of indefinite periods of operations with minimum Shuttle-tending.

In order to achieve the capability for research, construction, and space operations in the most economical manner practical, and to expand capabilities beyong the earlier stage of free-flying Shuttle-tended platforms, NASA will provide for manned operations in LEO with reduced dependence on Earth for control and resupply. Using the 25KW Power System, a habitation and various operations modules which could be outgrowths of preceding developments, the permanent/manned LEO facility will evolve in the later 1980's to be fully operational by the end of the decade."

Twelve space station and space structure studies were reviewed to determine the characteristics of projected space structures. The following four pages overleaf summarize characteristics of 12 representative space structures considered in this study.

EVOLUTION OF SPACE PLATFORM CAPABILITIES



Source: OSTS Activities Plan, FY '81 (draft)

REPRESENTATIVE SPACE STRUCTURES

Twelve representative space structures were studied to identify typical ECWS task and performance requirements. These structures represent concepts under consideration by various NASA centers and Aerospace Prime Contractors. The following characterizes the structures:

- They represent the extremes of size and weight.
- They represent the variety of proposed construction techniques.
- They all require the ECWS to support their construction.
- They are all so large as to require at least one Shuttle launch.
- They favor on-orbit fabrication or assembly over on-orbit deployment to achieve high payload launch packing density required for economical Shuttle launching.

Structures fall into three groups:

- Large Power Modules

  Large Power Modules to provide free-flying modules with approximately 250KW of power to support manufacturing and test. Projected time for this activity is the late 1980's.

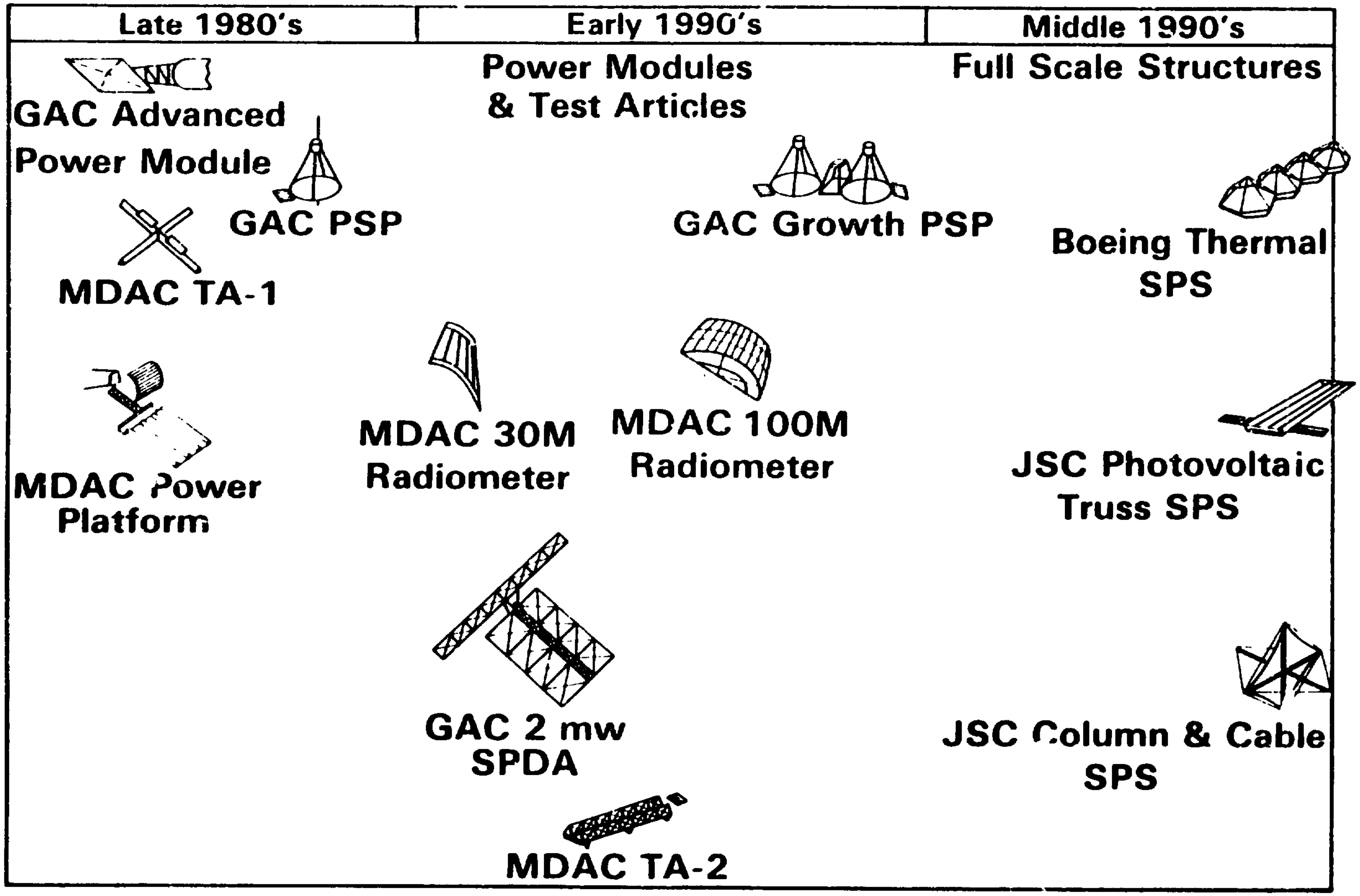
- Structure Demonstration and Test Articles

  A group of development and test structures to develop fabrication techniques and to answer questions relative to thermal and structural stiffness and intended function. Projected time for this activity is the late 1980's and early 1990's.

- Full Scale Structures

  The first group of operational solar power satellite systems, communications antennas, and reflectors is expected to be the mid 1990's.

REPRESENTATIVE TEST ARTICLES AND FULL SCALE STRUCTURES



GAC — Grumman Aerospace Corp
MDAC — McDonnell Douglas Aerospace Corp
PSP — Public Service Platform (Communications Satellite)
SPDA — Solar Power Development Article
SPS — Solar Power Satellite
TA — Test Article

SUMMARY OF MAJOR DEMONSTRATION AND TEST ARTICLES

Structure	Projected Construction Techniques	Dimensions		Major Elements									Construction Locale	Major OCSE				
		Size	Wt	Beams	Solar Array	Elect. Cabling	Gimbal Brg.	Brace Cables	Electronics/ Amplitrons	ACS	RF Panels	IUS to GEO		Crane/Cherry Picker	EVA Work Platform	Strongback/ Turntable	Beam Builders	Holding Fixtures
GAC Advanced Power Module	Fab/Dep/ Assy	App 35M + 70M	25K kg	1M	X	X	X		X				Const & Use in LEO	X	X	X	X	
GAC 2 mw SPDA	Assy/ Deploy	Antenna 6M + 200M	8 kg								X		Const & Use in LEO	X	X	X		X
	Fab & Deploy	Solar Array 196M + 111M	24K kg	1M	X	X	X		X	X				X	X	X	X	X
GAC PSP	Not Defined	61M Dia + 61M	27K kg	X		X	X		X	X	X	X	Const in LEO Use in GEO	X	X	X	P	
MDAC TA 1	Fab/ Deploy	Cruciform 123M + 125M	6K kg	2M + 15M		X			X	X		X	Const in LEO Test in GEO	X	X		P	X
MDAC Power Platform	Fab/ Deploy	105M + 28M		1M	X	X	X		X	X			Const & Use in LEO	X	X		X	X
MDAC TA 2	Fab/Assy & Deploy	Solar Array 30M x 250M	22K kg	10M	X	X	X		X	X			Const & Use in LEO	X	X	X	P	X
	Fab & Deploy	Antenna		0.1M							X		Const & Use in LEO	X	X	X	P	X
MDAC 30M Radiometer	Fab/ Assy	30M Dia	500 kg	1M						X	X		Const & Test in LEO	X		X	P	X
MDAC 100M Radiometer	Assy	100M Dia x 50M High	2900 kg	1M						X		X	Const in LEO Test in GEO	X	X	X		X
GAC Growth PSP	Not Defined	140M + 61M x 61M		X		X	X		X	X	X	X	Const in LEO Assy to PSP at GEO	X	X		P	X

Not Required
X - Required
P - Possibly Required
OCSE - Orbital Construction Support Equipment

SUMMARY OF REPRESENTATIVE DEMONSTRATION AND TEST ARTICLE CONSTRUCTION ELEMENTS

This listing typifies the range of element types that comprise representative demonstration and test articles. This list is drawn from the preceding tabulation of demonstration and test article characteristics, and forms the basis for identifying ECWS tasks and requirements discussed in the following section of this report.

Element	Weight	Dimensions
IUS Stages	30,000 kg	2m Dia. x 20m Long
Cargo Pallets	15,000-30,000 kg	5-20m
Construction Jigs	8700 kg	40 x 110 x 7m
Complete Assemblies	7800 kg	30 x 250m
Composites Fabrication Module	4660 kg	4.4m Dia. x 15m
Brace Cabling	1300 kg	2m Dia. x 1m
Rotary Joint	165 kg	1m x 1m x 1m
Electronics Pkgs	75 kg	0.5m x 0.5m x 0.5m
ACS Pods	60 kg	1m x 1m x 1m
Worksite Platform	25 kg	1.5m x 0.5m x 0.5m

CREWMAN EVA TASKS

This study identified four classes of EVA operations associated with payloads:

- Positioning construction equipment and materials.
- Construction, consisting of fabrication, assembly and deployment.
- Checkout, activation and use of structure for its intended purpose.
- Servicing, maintenance and repair.

The four classes comprise 46 construction and payload tasks. They were analyzed to define EVA work task requirements. The 46 EVA construction and payload tasks were also grouped into two types of crewman EVA tasks, as shown on the following page:

- Using tools to perform manual operations.
- Positioning and manipulating objects of various sizes.

The following definitions apply throughout this report:

- Fabricate - Manufacture low density structure in orbit from high density bulk material launched from Earth.
- Assemble - Connect together in orbit previously manufactured elements.
- Deploy - Erect in orbit a previously folded or rolled structure.
- Small Object - Characteristic dimensions - Length $<$ 0.25 m, or Mass $<$ 0.25 kg.
  Crewman requires hand strength, finger dexterity or both.
- Medium Size Object - 0.25 m $\leq$ length $<$ 2 m, or 0.25 kg $\leq$ Mass $\leq$ 150 kg.
  Crewman uses one or both arms and upper body.
- Large Object - Length $>$ 2 m, or mass $>$ 150 kg.
  Crewman uses whole body forces.

TYPICAL CREWMAN EVA TASKS

- Use of Tools and Manual Operations
  - Cut/Trim
  - Make Holes
  - Install Mechanical Fasteners
  - Fasten by Welding or Fuse-Bonding
  - Use Alignment and Checkout Equipment
  - Remove/Install Access Panels
  - Clean/Service
  - Replenish Expendables
- Position and Manipulate Objects
  - Manipulate Small Objects
  - Position Medium and Large Structure Elements

EVA TASK REQUIREMENTS

EVA task issues drive ECWS requirements. The following conclusions drawn from studying these task issues define broad ECWS requirements.

Mobility and Strength - Strength demonstrated in performing Skylab EVA tasks is adequate to perform EVA construction. Shuttle EMU mobility (joint range and torque) is also adequate to support EVA construction. Therefore, construction can use existing EVA strength and mobility capability, and does not require mechanization. Shuttle EMU mobility levels comprise ECWS baseline levels.

Skill Levels - Skill requirements consider both difficulty of performing tasks and susceptibility to damage of workpieces. Most EVA construction tasks require low or moderate skill levels. Thus most EVA construction tasks will not be constrained by skill requirements. Only three typical EVA construction tasks require high skills: electrical wiring repair, alignment of structural elements and freehand welding.

Manpower Levels and Proximities - Most EVA construction tasks can be performed by one person. Positioning and aligning large structure sections can be performed with two crewmembers. The two crewmembers must be able to see each other, which necessitates wide angle visibility. In many operations, crewmembers may be several hundred meters apart performing alignment or other solitary tasks. This necessitates a one-person ECWS concept.

Restraints and Workstands - Twenty-nine restraint concepts were evaluated. The Skylab foot restraint and "astrogrid" concepts are recommended. Two workstands were concepted and analyzed: a construction workstand using the Skylab foot restraint, and an astrogrid approach for satellite service.

Lighting - Area lighting and local lighting levels were identified. Area lighting can probably be turned off 62% of the time when the structure is in sunlight. Local lighting levels from 30 to 200 foot candles will be required up to 100% of the time, depending on ambient light levels, light-to-shadow contrast and fineness of task being performed.

Tools - Apollo and Skylab experience showed that with adequate body restraint an EVA astronaut could work effectively with simple hand tools. Torque-cancelling features were not required. The following list of tool types contains the special and general purpose tools required to perform the ECWS EVA tasks. ECWS tool types will probably be similar to their earthbound counterparts except for the characteristics in the following list.

EVA TASK REQUIREMENTS (CONTINUED)

ECWS TOOL TYPES

- Saw, file, shear
- Drill, ream, punch
- Fastener drive, rivet, pin expansion
- Fuse bond, adhesive bond, induction heat, electron beam weld
- Specialized alignment, diagnostic and checkout equipment.
- Fluid servicing equipment
- Cleaning supplies and wipes
- Assorted hand tools

ECWS TOOL CHARACTERISTICS

- Will not overheat in vacuum
- Withstand space environment
- No-glare reflection
- Contain debris control
- Improved safety guarding
- Compatible with guide fixturing
- Tetherable/capturable
- Compatible with gloved hand or end effector
- Provisions for local lighting
- EMC compatible
- DC operation
- Minimal handling of individual tool bits and drivers

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EVA SORTIE DURATION AND FREQUENCY

Projected EVA construction missions were compared with pipeline construction activity, shipboard duty and Shuttle flights to identify acceptable workday and work week standards.

	SHUTTLE EVA	PIPELINE	SUBMARINE
Shift, hr	7 hrs EVA	6 hours	6 hours
Shifts per day	1	2	1 per 18 hr day
Work days per week	6	7	Continuous
Mission or duty length	7 to 30 days	3 weeks	6 mo. to 1 year
Time off between missions	TBD	1 week	1 to 6 months

Recommended ECWS Sortie requirements are:

Sortie length	6-8 hours
Sorties per day	1
Sorties per week	6 days/week for 30 to 180 days
Time off between flights	6 months

Mission duration and Sortie recommendations drive ECWS equipment life requirements as follows:

- Per mission: 8 hr/Sortie x 6 Sorties/7 days x 180 days/mission = 1,232 hrs/mission.
- Calendar Life: 1 mission/year with ground maintenance for 10 years = 10 year life.
- Operating Life: 10 missions x 1,232 hrs/mission = 12,320 hours.

EVA ENCLOSURE PRESSURE AND GAS COMPOSITION

Current EVA requires approximately three hours of prebreathe on pure O_2 prior to depressurizing the airlock to avoid "the bends". Prebreathe is an undesirable constraint on construction EVA because it is time consumming, tedious and reduces EVA planning flexibility Elimination of prebreathe is an ECWS goal.

Elimination of prebreathe depends on the proper combination of cabin and suit gas pressures and compositions. Selecting gas composition and pressures impacts weight, power and equipment within the habitation module and space shuttle as well as impacting ECWS equipment, weight, volume and mobility. Oxygen toxicity must also be considered. Prebreathe can be eliminated if cabin N_2 pressure ≤ 1.5 the EVA suit pressure. This sets the limits of the suit and cabin pressure relationship as follows using 3 psia O_2 in the cabin:

- 4 psia suit with 9 psia cabin
- 8 psia suit with 14.7 psia cabin

Significant findings of the study drive the suit and cabin gas pressure recommendation toward both of these limits. Factors favoring the 9 psia cabin and 4 psia suit are:

- Reduced cabin N_2 leakage and vent flow power
- Reduced ECWS leakage, power and emergency system size
- Acceptable suit and glove mobility and life have already been demonstrated
- O_2 toxicity prohibits long term use of 8 psia suit with pure O_2

Factors favoring the 14.7 psia cabin and 8 psia suit are:

- Reduced cabin cooling fan power
- Improved cooling of air-cooled cabin avionics
- Reduction of potential material flammability

EVA ENCLOSURE PRESSURE AND GAS COMPOSITON (CONTINUED)

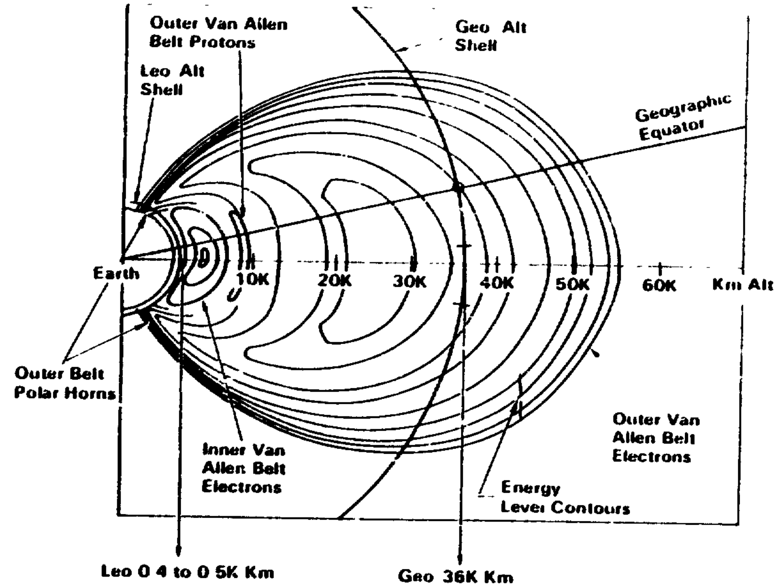
Evaluation leads to recommending a 4 psia pure O_2 ECWS in conjunction with a 9 psia cabin. The cabin atmosphere consists of 3 psia O_2, which is the normal sea level value, plus 6 psia N_2. This atmosphere is similar to the 10 psia cabin atmosphere recommended in the JSC Space Station System Analysis study. While 4 psia O_2 is recommended for ECWS, it is further recommended that the suit be developed to operate at 8 psia in case a 9 psia cabin pressure proves to be unacceptable in the future. Factors which potentially could make a 9 psia cabin unacceptable include Spacelab or life sciences experiments, inability to manage air-cooled avionics heat loads and incompatability with international rescue vehicle with a 14.7 psia cabin.

RADIATION ISSUES

Radiation issues are a significant element of the ECWS study program. It is recognized that construction operations in Earth orbit will pose a significantly higher radiation problem to EVA than Apollo lunar surface activity, because lunar surface EVA operations were relatively short and construction operations will take place in or near the Van Allen belts. Conclusions drawn from the ECWS radiation analysis show that reasonable amounts of EVA can be performed at all projected orbits, but that radiation protection for the crew will have to be provided both by the vehicle and the space suit.

Radiation exposure drives ECWS shielding requirements. The following radiation exposure standards and models were used to define shielding requirements.

VAN ALLEN BELTS



- Radiation Dosage Standards – Defined by NASA for Shuttle, JSC 07700, Vol. X Rev. B.
- Environmental Models – Provided by McDonnell Douglas

LEO	– Electrons:	AE-5 Solar Minimum
	Protons:	NASA SP-3024 Vol. 5 extended to 50 mv and Vol. 6
GEO	– Electrons:	AE-7 High

- Baseline Mission Model – 154 8-hour EVA Sorties per 180 day mission. Baseline vehicle has 0.1 in. aluminum skin. Spacesuit is equivalent to Shuttle EMU. Radiation exposure uses 60% of dosage standard for Van Allen belt radiation exposure during scheduled EVA. This leaves 40% of dosage standard for unscheduled EVA's and solar flare exposure.

LEO – EVA planning is not constrained by orbits passing through the South Atlantic anomaly or polar horns. EVA requires the following additional amounts of shielding over a suit of equivalent Shuttle EMU construction:

Inclination	28½°		55°	
Altitude, km	400	500	400	500
Additional Shielding Req'ts, lb.	0	9	17	25
Vehicle Thickness, in. Al or equiv.	0.1	0.1	0.2	0.2

Transorbit to GEO – A chemically fueled orbit transfer vehicle performs a Hohman transfer between LEO and GEO in 5.25 hours, passing through the highest intensity region of both Van Allen belts. The following shielding applied the vehicle wall or crewmembers will preserve 90% of the scheduled EVA dosage exposures per round trip.

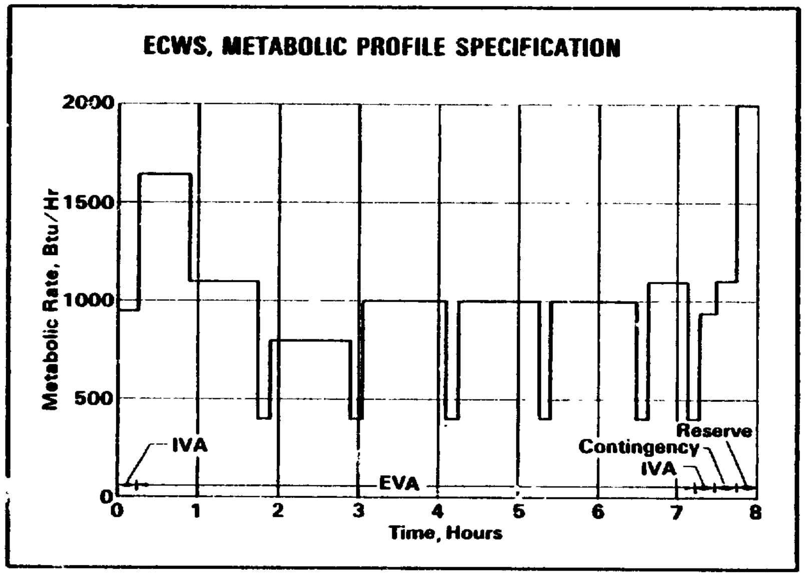
Vehicle Wall	Eye Shielding	Skin Shielding
0.49 in. Al or equiv.	N/R	N/R
0.27	0.22	N/R
0.16	0.33	0.11

GEO – EVA may be planned anytime. Based on a 4 in. thick aluminum cabin wall, which also provides refuge from solar flares, EVA requires shielding equivalent to 0.277 in. Al, which weighs approximately 70 lbs. This is adequate protection to support a 180 day mission with 154 8-hour EVA's including the transorbit round trip.

ECWS METABOLIC PROFILE

Metabolic values for various ECWS tasks and sortie segments were estimated from actual Apollo and Skylab flight data and from NASA metabolic rate determination data.

Mission and Duration		Min	Avg	Peak	Total Btu
		Metabolic Rate (Btu/hr)			
Apollo Trans Earth (1.37 hrs)	Spec.	400	1200	2000	1640
	Actual	484	1080	1635	1480
Apollo Lunar (4 hrs)	Spec.	400	1200	2000	4800
	Actual	488	913	1091	3652
Shuttle (7 hrs)	Spec.	400	1000	1600*	7000
ECWS (8 hrs)	Spec.	400	1000	1650*	8000



*In addition to 15 minute reserve at 2000 Btu/hr

ECWS GUIDELINES AND REQUIREMENTS SUMMARY

Study of ECWS work tasks and performance requirements led to defining ECWS guidelines and requirements, which are summarized as follows:

Guidelines - Operational aspects affecting ECWS use:

- 2 person EVA teams for safety. Radio communication between EV and IV crew.
- Tethering or restraint required at worksite for crew, tools and materials.
- Low to moderate skills required for most tasks. 0-g adaptation of 1-g tools required.
- Structure edge, corner and protrusion requirements same as for Shuttle payloads.
- EVA not constrained by light/dark orbital periods or passage through South Atlantic anomaly.
- ECWS don/doff, recharge and stow in airlock.
- In-flight replacement of modular ECWS items.

Requirements - ECWS design and performance requirements:

- Single person EVA system.
- Planned EVA sortie length up to 8 hours.
- Prebreathe not required. 4 psia ECWS with 9 psia cabin recommended.
- Mobility and life support system performance requirements similar to Shuttle EMU.
- Metabolic performance: 1000 Btu/Hr average, 400 Btu/Hr minimum, 1650 Btu/Hr maximum, 2000 Btu/Hr peak (15 min), 8000 Btu total per sortie.
- 4-8 psi capability in suit.
- Life requirements: 10 calendar years, 12,320 hours, 5 million cycles on major joints.
- Automatic visoring and wide angle vision required.
- Radiation protection required for all orbits except 28 1/2° 400 km.
- 1/2-hour emergency life support provisions required.

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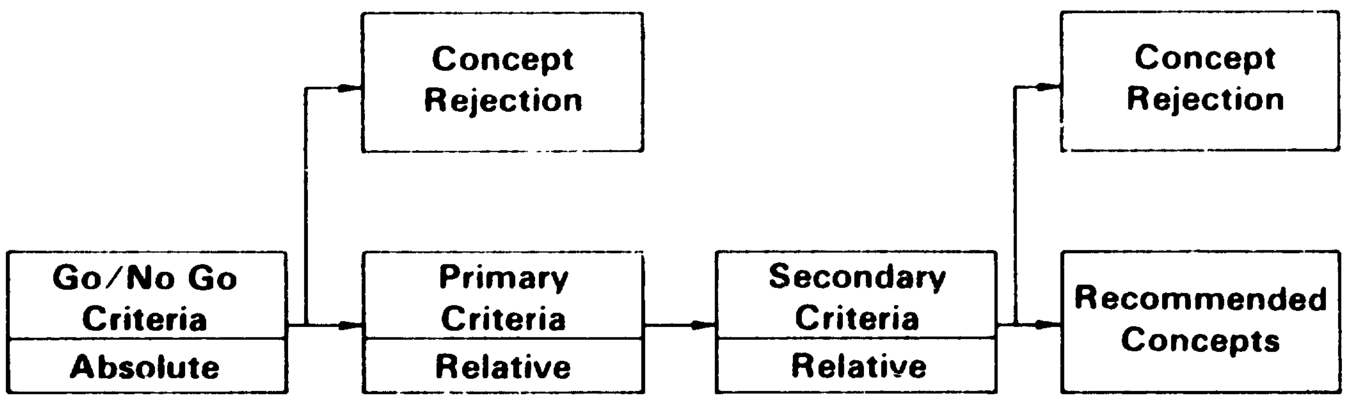
CONCEPT SELECTION

Concept selection consists of establishing evaluation criteria, identifying candidate equipment concepts and evaluating concepts against the criteria. ECWS study program considers three major equipment concept areas: life support subsystems, life support packaging and EVA enclosure. The three areas are distinctly different from another, so different criteria were applied, as shown below:



Go/No Go Criteria (Absolute)	Primary Criteria (Relative)	Secondary Criteria (Relative)	Recommended Concepts
Performance Safety Availability Crew acceptability	Vehicle weight EVA volume Cost Reliability Flexibility	Vehicle volume EVA weight Interface compatability Maintainability Operability	<u>Life support subsystems</u>
Safety	EVA volume Reliability Flexibility	EVA weight Maintainability Operability	<u>Life support packaging</u>
Performance Safety Availability Crew acceptability	Cost Reliability Flexibility	Vehicle volume Interface compatability Maintainability Operability	<u>EVA enclosure</u>

CONCEPT IDENTIFICATION AND EVALUATION

ECWS equipment concept recommendations, summarized on the next six pages, resulted from evaluating sixty-two different concepts. Forty-two concepts involve the life support system, fifteen involve the EVA enclosure and five involve ECWS integration and workaids.

The forty-two life support concepts were evaluated quantitatively using the following four step procedure:

- Each concept was evaluated numerically according to a rating scale for each criterion.
- Criteria were weighted relative to one another.
- The weighting was varied to reflect macroscopic changes in the STS program. For example concepts requiring new technology are not available in the near future. These concepts did not pass the go-no/go criteria for early STS use, but were considered for later use. Similarly, concepts that use water as a consummable were down-rated for use when STS becomes solar powered. This reflects reduced availability of consummable water after solar power supplants cryo-supplied fuel cells.
- The weighted ratings for each concept were summed and the high scorers were selected.

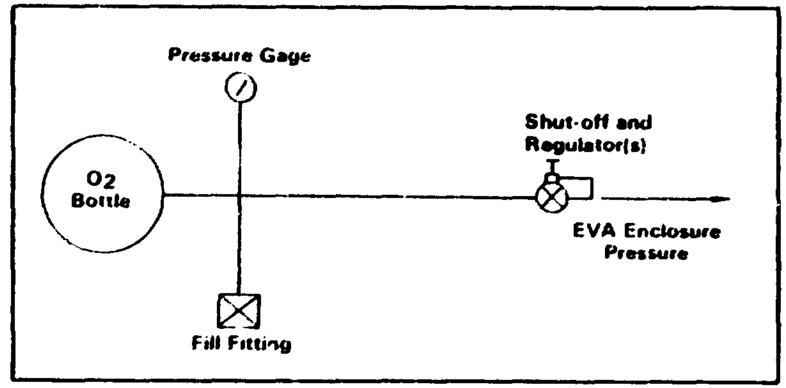
Quantiative evaluation requires a sufficiently large data base to establish meaningful rating scales for each criterion. This data base does not exist for EVA enclosure, work aids and integration concepts; so these concepts were evaluated qualitatively against the EVA enclosure criteria shown on the previous page.

The remainder of this section presents a brief description of the selected concepts, along with major reasons for their selection.

LIFE SUPPORT SUBSYSTEM SELECTION

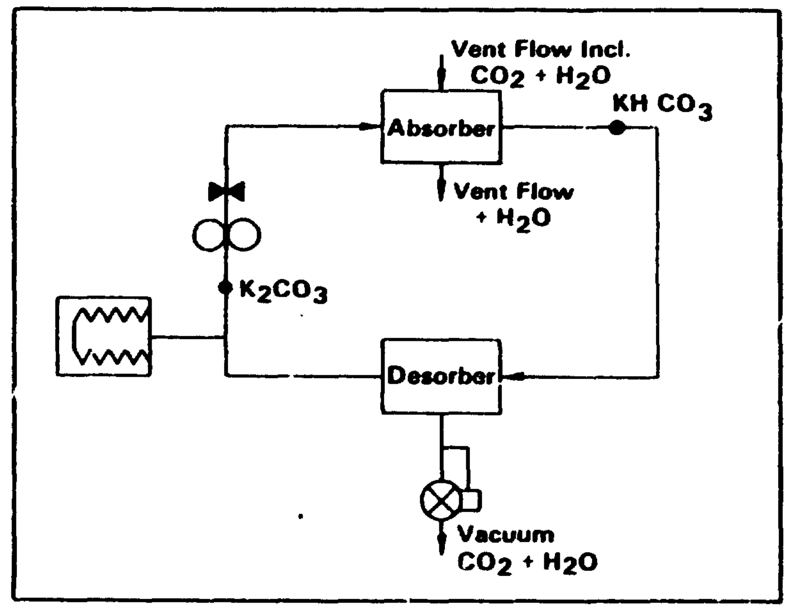
Oxygen supply

- 3000 psi GOX selected for primary supply. Refillable from vehicle water electrolysis system.
- 6000 psi GOX selected for emergency supply. Non-refillable in flight.
- Lowest EVA volume, lowest vehicle weight.
- 5 O_2 supply concepts were evaluated.



CO_2 removal

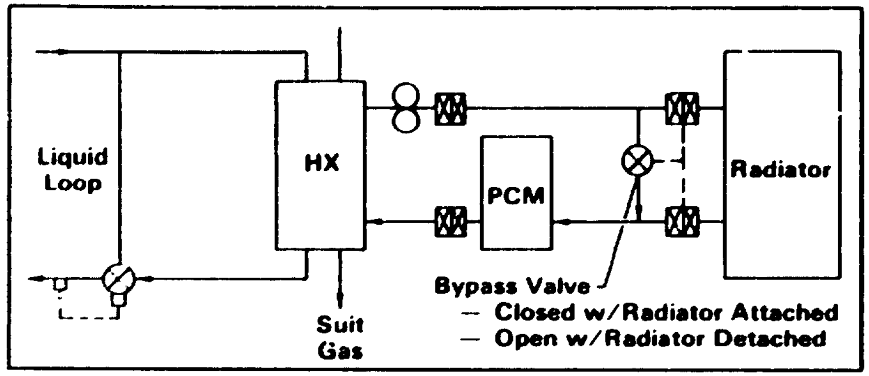
- K_2CO_3 membrane concept selected for late 1980's
- Requires technology development for late 1980's use
- Lowest vehicle weight coupled with low EVA volume
- 8 CO_2 removal concepts were evaluated



LIFE SUPPORT SUBSYSTEM SELECTION (CONTINUED)

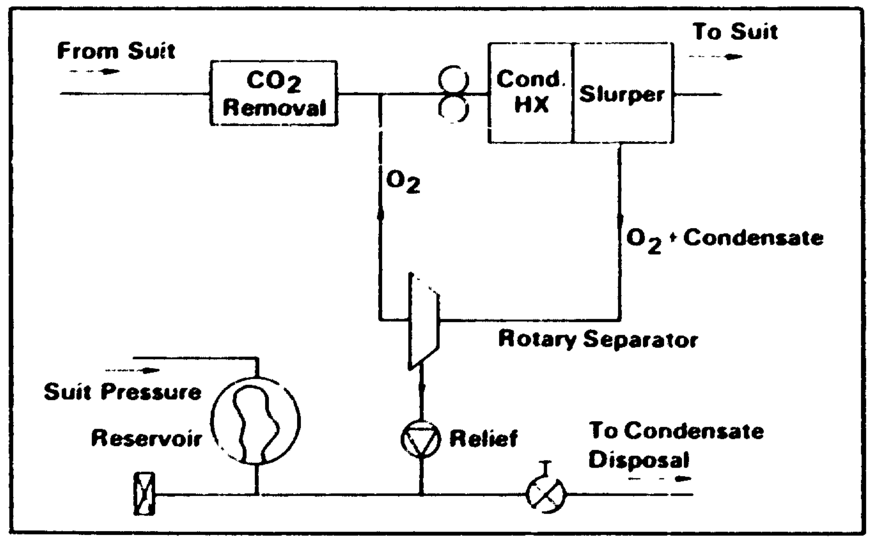
Heat Rejection

- Hybrid heat sink concept selected for use with solar-powered vehicle. Uses 4 hour refreezable phase-change-material (PCM) and detachable radiator
- Radiator area approximately 15 ft^2
- Lowest vehicle weight coupled with low EVA volume
- 9 phase-change materials evaluated
- 5 heat rejection system concepts evaluated

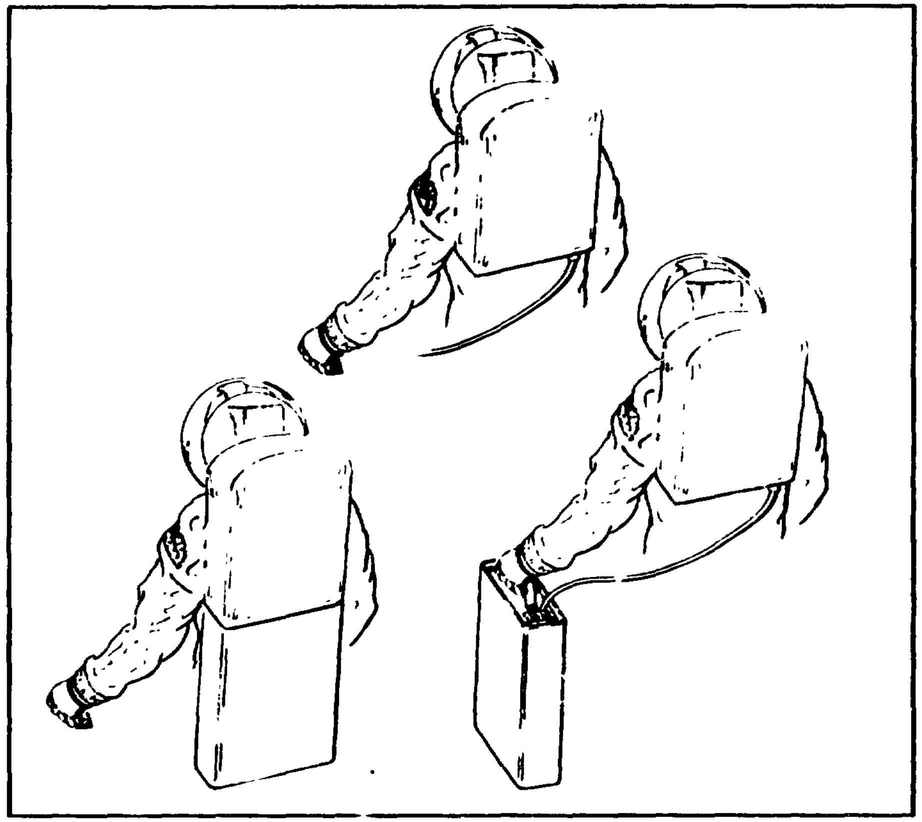


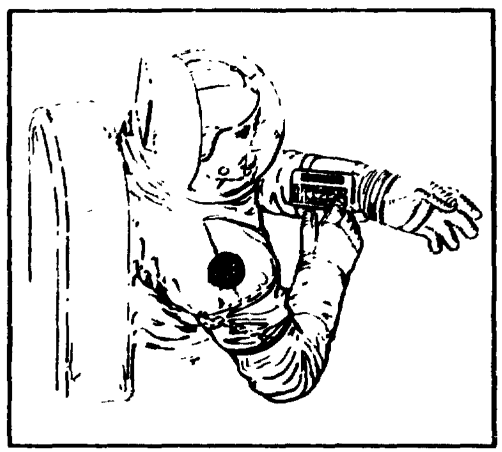
Condensate Management

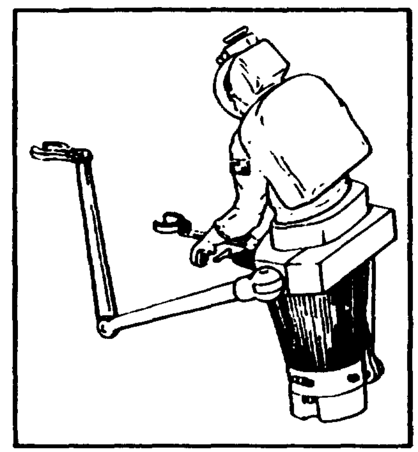
- Slurper/Rotary Separator concept selected
- Similar to Shuttle EMU concept
- Not clearly superior to scupper/rotary separator concepts, but selected to utilize current EMU development
- 7 condensate management system concepts evaluated



LIFE SUPPORT PACKAGING AND INTEGRATION







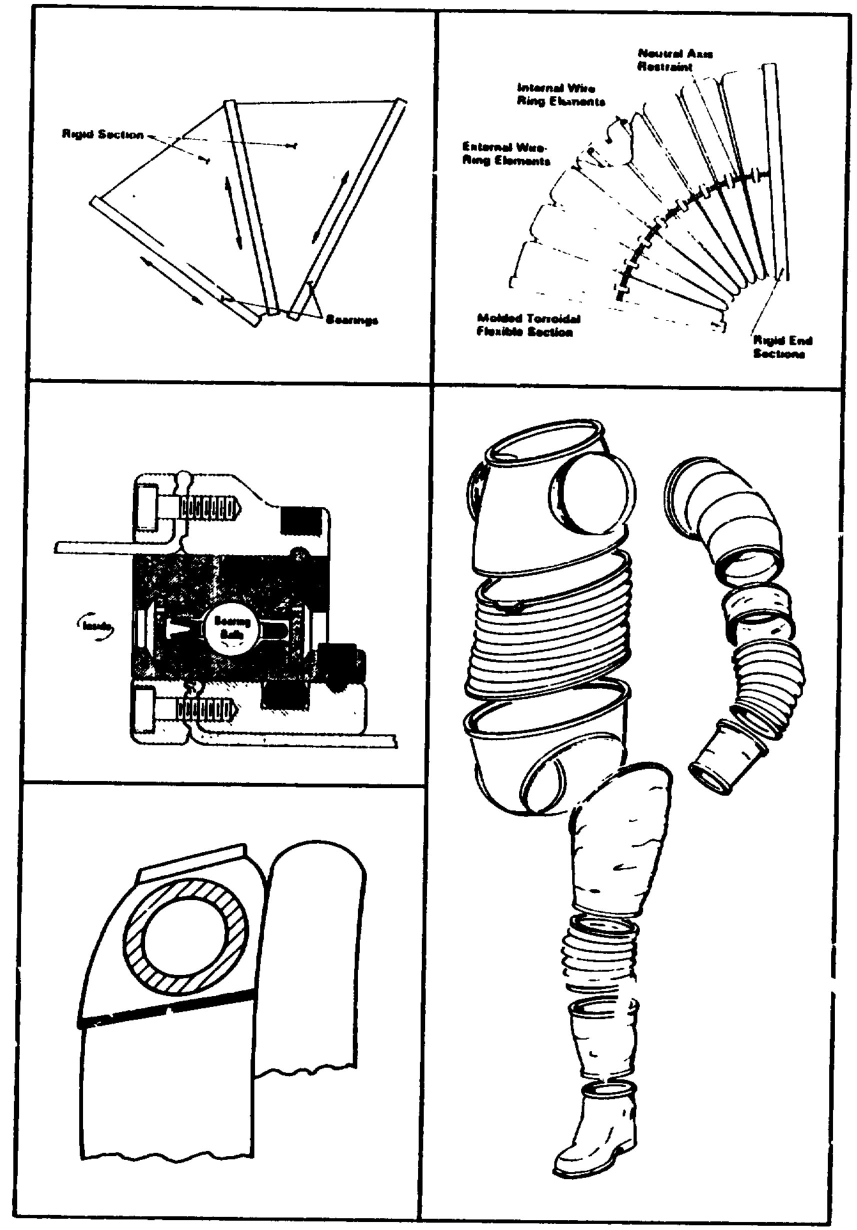
Packaging

- Convertible packaging selected. Compatible with free-flying, fixed worksite and random location worksite requirements
- Atmosphere revitalization, communication, caution and warning and emergency functions always worn on the back
- O_2 supply, power and cooling in separate package. Can be worn on the back or hand-carried for setting down at worksite
- Can use vehicle-supplied consummables at fixed worksites
- 8 packaging concepts evaluated

Integration

- Microprocessor controls LSS function
  - Valve actuation
  - Temperature control
  - Caution and warning
- Wrist-mounted keyboard — display unit is crewmember interface
- Leg-can integrates with radiator and manned maneuvering module
- Optional manipulator module provides long reach and strong grip

EVA ENCLOSURE



Softgoods

Joints

- 4 section stovepipe joint selected for shoulder. Has long life and can be made tapered for reduced arm bulk.
- Torroidal joints selected for other major joints — long life, low friction
- 4 joint types evaluated

Construction

- Single-wall laminated modules integrate bladder and restraint. Tubeless tire is analogy.
- Modular soft goods are replaceable in flight
- Tough, puncture and abrasion resistant, smooth inner surface easily cleaned
- 2 softgoods construction evaluated

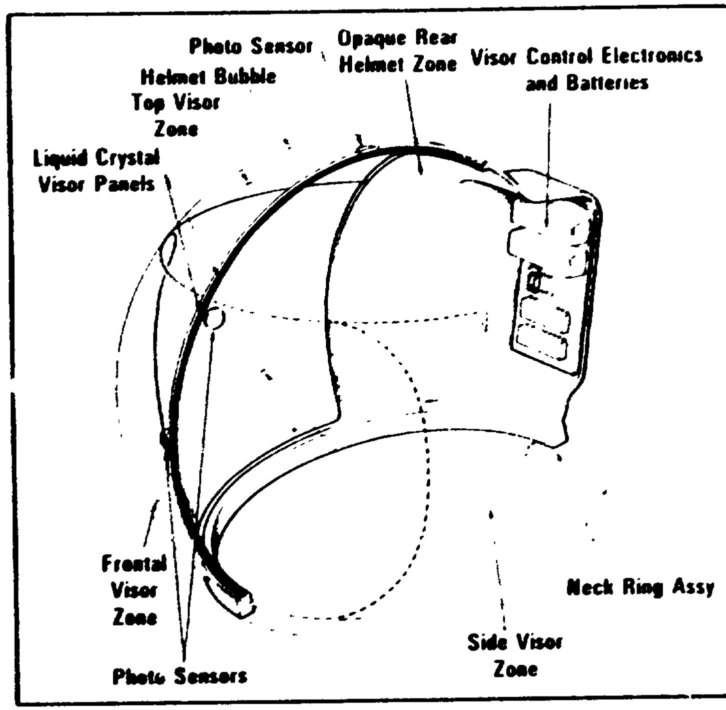
Upper torso

- Hard upper torso with single-plane entry closure, movable scye bearings and close-coupled LSS selected
- High reliability, easy to use, currently being developed for EMU
- 2 upper torso configurations evaluated

Hazards protection

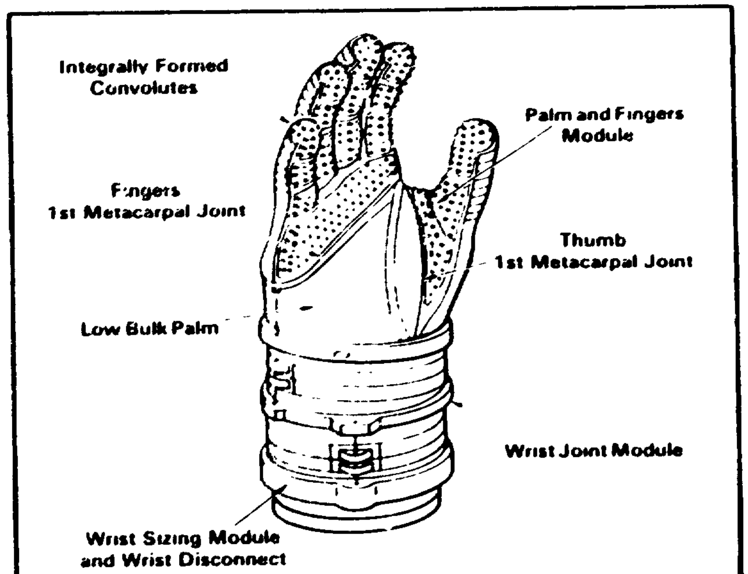
- Consists of thermal insulation, mechanical hazards protection and radiation protection
- Radiation protection tailored prior to flight for radiation in mission orbit
- Hazards protection applied as overgarment to softgoods modules

EVA ENCLOSURE (CONTINUED)



Helmet

- Clear bubble provides wide angle vision
- Liquid crystal panel provide automatic, hands-off visoring
- Automatic visoring requires technology development
- 2 automatic visoring concepts evaluated



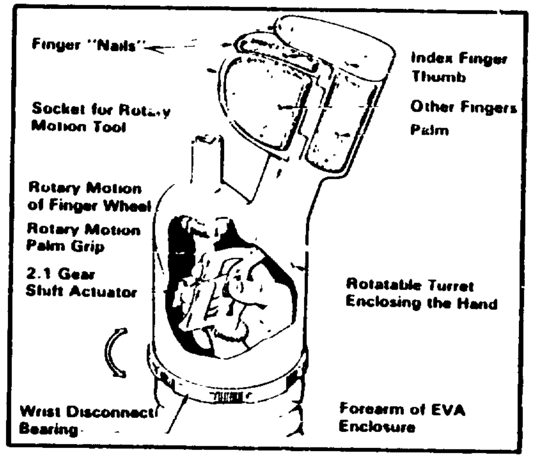
Gloves

- 3-module design permits sizing and on-orbit maintenance
- Pin-type thermal insulation retains tactility
- Wrist and finger joints use demonstrated technology
- 3 glove constructions evaluated

WORK AIDS

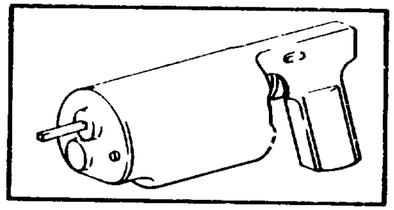
Manual Tool Adapter

- Hand-like manipulator to reduce fatigue of working with pressurized EVA glove
- Replaces one glove. Uses bare hand inside rigid, pressurized enclosure.
- Has thumb-to-forefinger, thumb to all fingers and palm-to-fingers motion.
- Has selectable 2:1 hand squeeze for high grip applications.
- Has separate rotary and high torque motion capabilities for fastener manipulation.



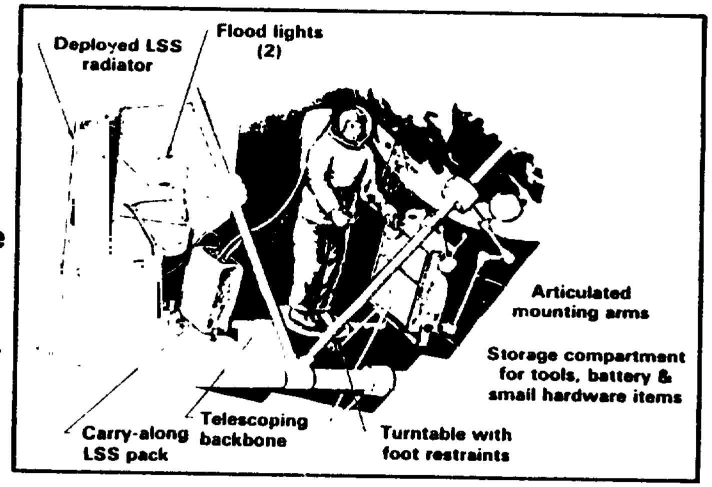
Power Tool Adapter

- Consists of power handle and replaceable tool modules.
- Has reciprocating and reversible rotary motions, variable speed and selectable speed-torque characteristics.
- Powered by 2-ECWS rechargeable batteries
- Performs drill, saw, shear and rivet operations
- Tool bit handling not required — magazine fed
- Integral debris collection



Workstand

- Easily mounted to 10 cm, 20 cm and 1 m diameter structure
- Workstand position easily adjusted
- Provides crewmember turnaround capability
- Stows tools and materials, mounts radiator and LSS carry-along package



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EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 1, Executive Summary

- Introduction
- ECWS Work Tasks Req'ts
- ECWS Performance Req'ts
- Concept Selection
- ECWS Preliminary Design
- Satellite Service Analysis
- New Technology Req'ts

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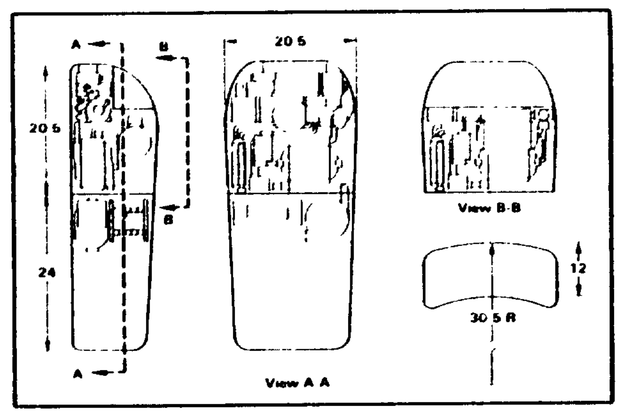
ECWS WEIGHT AND VOLUME

ECWS EVA Enclosure	Inc., °	28½		55		0 (GEO)
● Weight depends on orbit	Alt. km	400	500	400	500	36K
● "Large" size enclosure with flexible legs, including helmet and gloves		143	151	159	167	212 lbs
● Size is 74 in. tall x 32 in. wide at shoulders x 14 in. deep at body seal closure						
● Same as above but with rigid leg can and integral radiator. Leg can is 14 in. deep x 16 in. wide x 52 in. high.		170	174	179	183	233 lbs



Life Support System

- Consists of two packages
  - Upper — Communications, caution and warning, emergency, atmosphere revitalization — 104 lbs
  - Lower — Power, O_2 supply, 4 hr. heat sink — 136
  - 240
- Optional 15 ft^2 radiator — 25
- 265 lbs

ECWS WEIGHT AND VOLUME (CONTINUED)

	Weight	Volume
Portable Workstand	52 lbs.	60 in. x 16 in. x 18 in. folded
Power Tool Adapter		
- Motor drive unit	8	10 in. x 3 in. x 6 in.
- Drilling, sawing and fastener driving adapters	16	5 in. x 3 in. x 4 in. typical
- Battery Pack	24	12 in. x 7 in. x 6 in.
	48 lbs.	
Consummables	Per EVA Sortie	For 90 day resupply for 1-person EVA
3000 psi GOX	1.364 lbs	105 lbs.
Airlock O_2/N_2 for repressurization	5.5	425
		530 lbs.
Electric Power @ 18 VDC for battery recharge		
LSS battery	324 watt-hr	25 kw-hr
Lights battery	324	25
Power tool batteries (2)	648	50
	1,296 watt-hr	100 kw-hr
Limited Life Items		For 90 day resupply for 1-person EVA
Batteries (4)		48 lbs.
Body Stockings, worn under LCVG (11 changes)		6
EVA Gloves (2 pairs)		12
Tool Bits (3 sets)		12
		78 lbs.

THERMAL PERFORMANCE

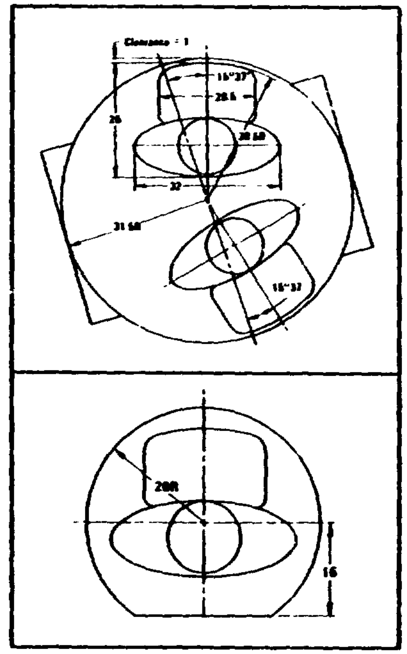
Case	Orbit	Structure	Q Metabolic Btu/hr	Q Environmental Btu/hr	Q Heat Rejection Btu/hr
Max hot	55° 400 km	Sun side of solar panel	2,000	138 into ECWS	2,164
Min cold	23½° 500 km	Shadow side of solar panel	450	365 out of ECWS	201
Nominal	26½° 400 km	50% shaded by open 10m truss	1,000	255 out of ECWS	763

AIRLOCK INTERFACE

Stowage — 2 ECWS' can be stowed in shuttle airlock. Modified ECWS-to-airlock mount req'd.

— 1m dia hatch has adequate clearance for passage

Recharge — Interface is via service and cooling umbilical which provides electricity and O_2 during recharge plus cooling and communication during don/doff and condensate draining.



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SATELLITE SERVICE CAPABILITY EVOLUTION

The following excerpt from NASA's Office of Space Transportation FY'81 Activities Plan (draft) shows macroscopic steps currently being planned to develop satellite service capability.

"Satellite Service

The objectives of the Satellite Service program are to define, develop, and demonstrate capabilities for placement, retrieval, and in-orbit maintenance and repair of satellites, and for retrieval of unstable satellites and space debris. Provision of those services in locations remote from the Shuttle imposes requirements that are considerably different from the requirements related to the provision of services near the Shuttle.

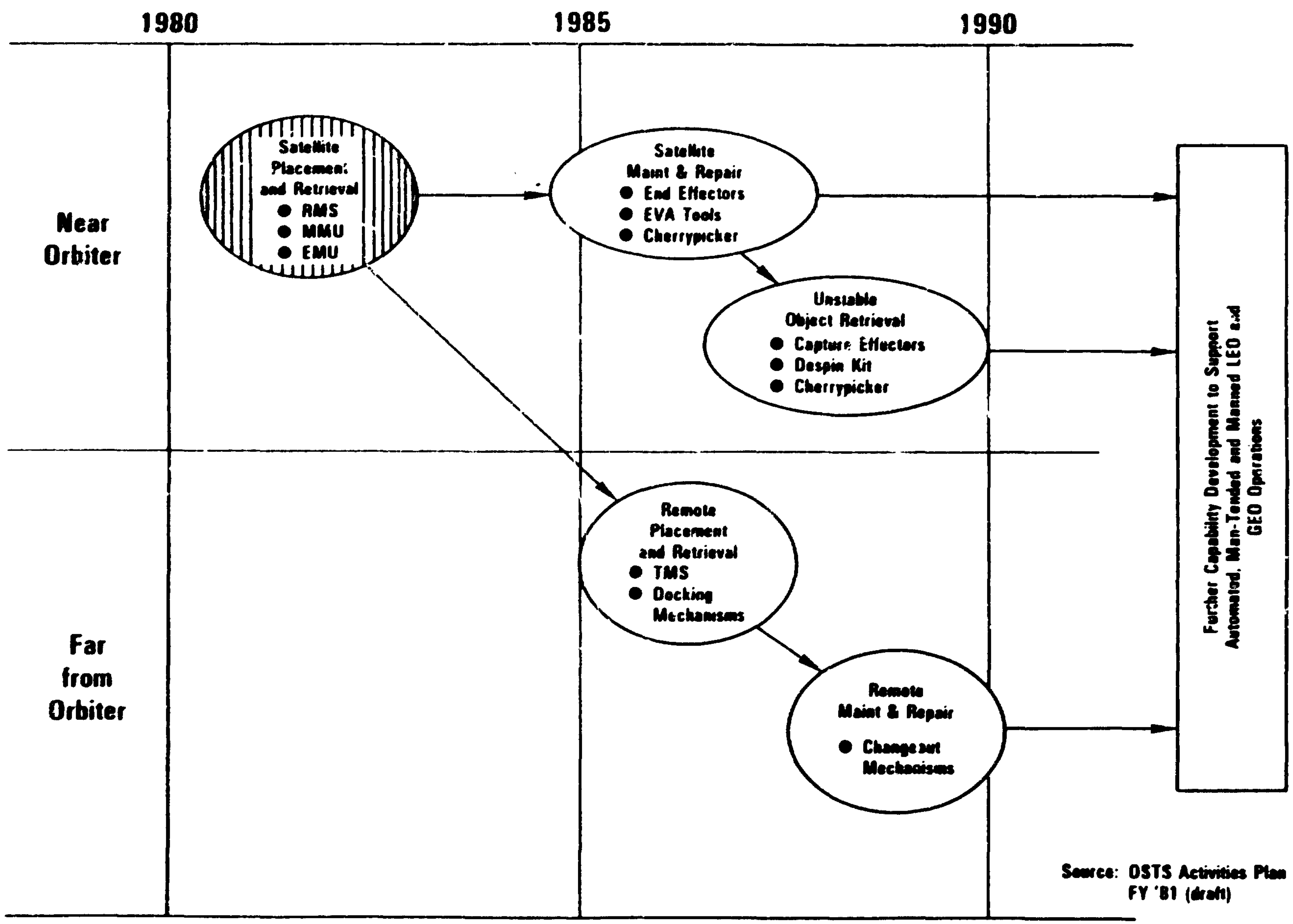
Services Near to Shuttle

The initial capability for satellite placement and limited retrieval will be provided by the Shuttle-mounted Remote Manipulator System (RMS), the integrated space suit and backpack, and the Manned Maneuvering Unit. However, space systems such as the Long Duration Exposure Facility, Multi-Mission Spacecraft, Space Telescope, and low-Earth-orbit science and applications platforms will require improved and new services, as well as equipment to provide those services.

Needed equipment will include such things as maintenance and repair equipment, berthing platforms, end effectors (mechanical hands) for the RMS, support equipment for Shuttle crewmembers to use in extra-vehicular activity (EVA) servicing operations, a remote work station called the "Cherry Picker" mounted to the free end of the RMS arm and television support systems. NASA plans to develop and demonstrate those items of equipment in the 1984-1985 period for subsequent operational use."

Most of the first 40 Shuttle flights, projected through 1984, are concerned with satellite orbital operations - deployment, retrieval and service. Projections for the remainder of the decade show increasing satellite launch rates and increasing launches of retrievable satellites.

EVOLUTION OF SATELLITE SERVICES CAPABILITY



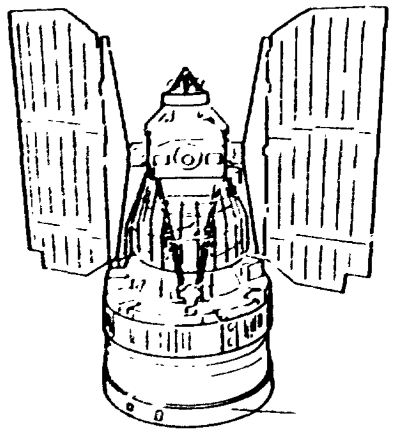
Source: OSTS Activities Plan FY '81 (draft)

REPRESENTATIVE SATELLITES

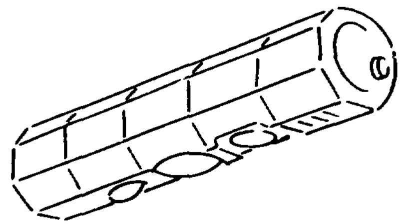
ECWS study program uses characteristics of seven representative satellites to identify EVA tasks associated with satellite orbital operations. The following tabulation highlights characteristics of seven representative satellites launched during the 1970's and projected for launch during the early 1980's. These satellites are illustrated on the following page.

Satellite	Launch year	Orbit n.mi	Geometry	Length ft	Diameter ft	Weight lb	Payload	Mission
Landsat	1972-77	560	cylinder	10	4	2,000	Photography	Earth resources study
HEAO	1974	340	Octagonal cylinder	19	9	10,000	X-ray & gamma ray sensors	High energy astronomy
Seasat	1978	430	Cylinder	35	6	4,000	Active & passive radar, IR	Ocean study & weather
LDEF	Early 1980's	300	12 sided cylindrical frame	30	14	User - dependent	Experiment trays	Exposure to space environment
Space Telescope	Mid 1980's	270	Cylinder	42	15	21,000	Optical telescope	Visible light astronomy
25 KW Power System	Mid 1980's	200-250	Box	34	10	28,000	Solar panels	Power for extended orbiter missions
MMS	Mid-late 1980's	270-864	Triangular Box	5+ payload	6	10,000	User - dependent	Multi-mission modular concept

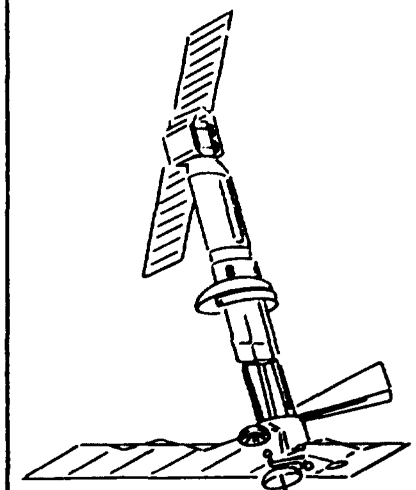
REPRESENTATIVE SATELLITES



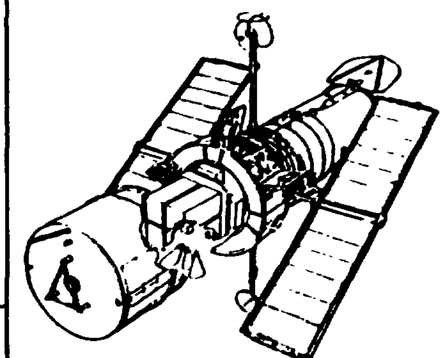
LANDSAT-1 Earth Resources Technology Satellite



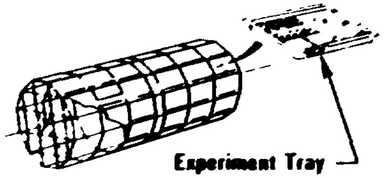
HEAO High Energy Astronomy Satellite



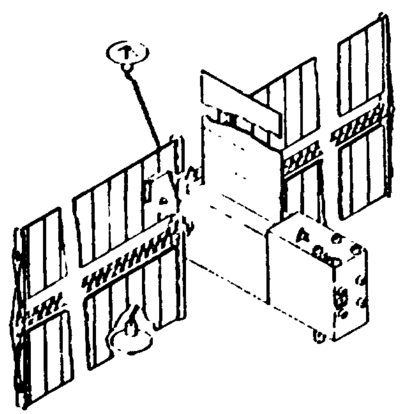
SEASAT-A Ocean Observation Satellite



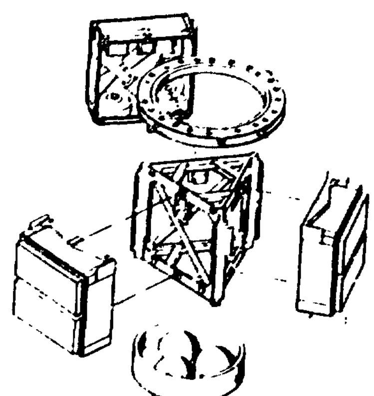
Space Telescope



Long Duration Exposure Facility



25 kW Power System (Concept)



MMS Multi-Mission Satellite (Concept)

EVA SATELLITE OPERATIONS

Three classes of satellite orbital operations have been identified:

- Deployment - Activation and release of satellites from Orbiter
- Retrieval - Return of satellites to Orbiter or vicinity
- Service - Resupply and/or recondition of satellites in orbit

Each class of operations consists of specific tasks listed below. This study's assessment of representative satellites indicates that EVA can effectively support satellite operations tasks either as the normal (baseline) mode or as the contingency (backup) made as shown in the accompanying chart. Two premises underly this assessment:

1. EVA is already baseline for some operations. Present NASA planning uses EVA as baseline for servicing the 25 kw Power System, LDEF, Spacelab and Space Telescope. EVA is also the backup for deployment and retrieval contingencies. EVA is expected to become baseline for more operations as EVA satellite operations experience increases.

2. EVA may become baseline for berthing assistance. Within the 50 foot RMS capture envelope Orbiter thruster plumes may impinge on satellites, making it difficult to null relative velocities. Relative velocities will have to be small because the maximum RMS velocity is 2 ft/sec. The RMS also has limited damping capability, and may be backdriven by forces greater than 23 lbs. Thus EVA assistance may be required for final positioning and motion damping between the RMS and satellite.

<u>Major Deployment Tasks</u>

- Deploy - Elevate satellite in payload bay and self-extend folded appendages.
- Assemble - Join previously manufactured elements together.
- Checkout - Assess satellite subsystem function, first using Orbiter power and then using on-board power.
- Release - Spin-up, if necessary, release and initiate sequence to propel satellite to final orbit
- Reboost - Replace propulsion module and repeat release sequence

PROJECTED EVA MODES TO SUPPORT SATELLITE OPERATIONS

	Deployment					Retrieval					Service					
Location	Deploy	Assemble	Checkout	Release	Reboost	Stabilize	Retrieve	Preberth	Berth	Debris Mgmt	Safetying	Checkout	Replacement	Refuel	Refurbish	Repair
Payload bay	C	N	C	C	N	—	—	—	N	N	N	N	N	N	N	N
RMS arm	C	N	C	C	N	—	—	N	N	N	N	N	N	N	N	N
Within 100m	—	—	—	—	—	—	C	N	N	N	N	N	N	N	N	N
Within 10 km	—	—	—	—	—	C	C	—	—	C	—	—	—	—	—	—

N = Normal (baseline)
C = Contingency (back-up)
— = Not applicable

EVA SATELLITE OPERATIONS (CONTINUED)

Major Retrieval Tasks

- Stabilize - Bring spinning or tumbling satellite under control for retrieval.
- Retrieve - Bring satellite to vicinity of Orbiter.
- Reberth - Deactivate subsystems and trim or fold a pendages prior to berthing.
- Berth - Attach satellite to RMS or payload bay adapter.
- Debris Mgmt. - Retrieve, collect and stow unserviceable satellite elements and orbiting debris for return to Earth.

Major Service Tasks

- Safetying - Disarm potentially hazardous subsystems and install protective shielding.
- Checkout - Check performance, condition and alignment.
- Replacement - Change modular elements.
- Refuel - Replenish expendable fluids.
- Refurbish - Clean sensitive surfaces, recalibrate instruments.
- Repair - Restore function of damaged, non-modular elements.

SATELLITE SERVICE TASKS AND TOOL REQUIREMENTS

Listing subsystems present in representative satellites establishes the framework for identifying service (resupply and reconditioning) tanks. The accompanying chart shows projected service operations for satellite subsystems.

The chart overleaf shows projected tool requirements for performing resupply and reconditioning tasks.

The balance of this section presents EVA equipment concepts for supporting satellite deployment, retrieval and service operations.

SATELLITE SERVICE TASKS

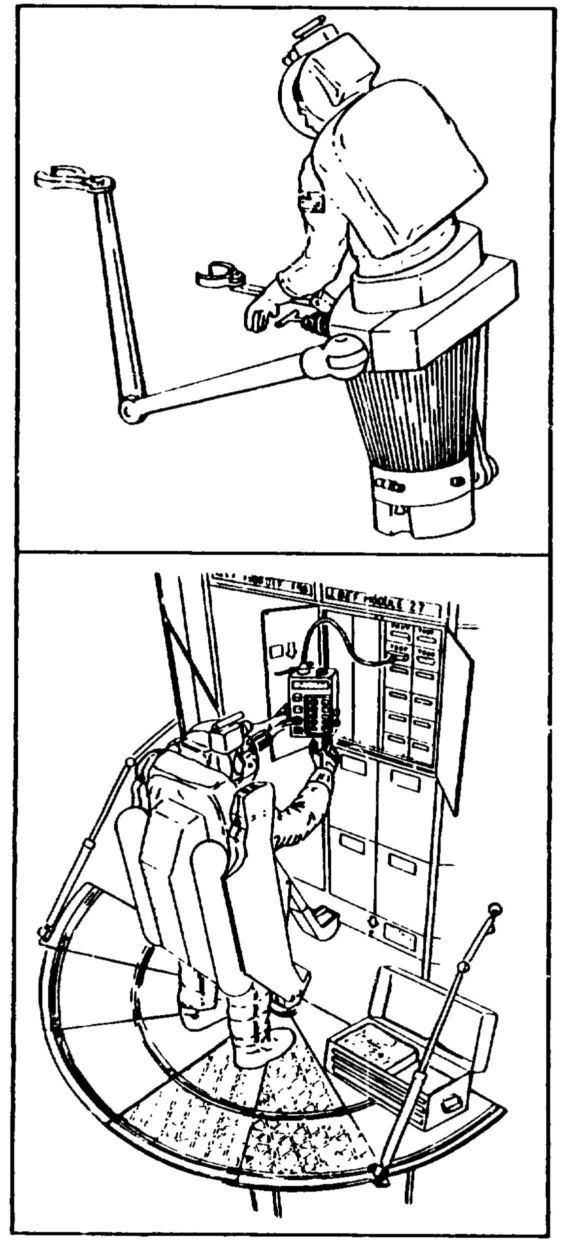
SATELLITE SUBSYSTEM

SERVICE TASK	ATTITUDE CONTROL	TANKAGE	POWER CONDITIONING	POWER SOURCE	SOLAR CELL	BATTERY	FUEL CELL	NUCLEAR	COMMAND & CONTROL	DATA HANDLING & SIG. COND.	HEAT REJECTION	PAYLOADS	PASSIVE EXPOSURE	PASSIVE SENSOR	ACTIVE RF	BIOLOGICAL	STRUCTURE
SAFETYING																	
MATE & DEMATE ELECTRICAL CONNECTORS			X		X	X	X	X	X	X	X			X	X	X	
ACTUATE SWITCH/BREAKER	X		X		X	X	X	X	X	X	X			X	X	X	
REMOVE ANTENNA									X								
SHIELD JAGGED/SHARP EDGES																	X
INSTALL & REMOVE THRUSTER BAFFLES	X																
SHIELD RADIATION SOURCES								X									
ISOLATE FLUIDS		X									X						
VENT PRESSURE VESSELS		X					X				X						
SHIELD PRESSURE VESSELS		X					X										
CHECKOUT																	
CHECK FLUID LEAKAGE	X	X									X						
CHECK ELECTRICAL CONTINUITY	X	X	X		X	X	X	X	X	X	X			X	X	X	
CHECK ITEM PERFORMANCE/CONDITION	X		X		X	X	X	X	X	X	X			X	X	X	
VISUAL INSPECTION	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X
GAUGE FLUID QUANTITIES		X									X						
MEASURE LENGTH & STRAIGHTNESS																	X
REPLACEMENT																	
MATE & DEMATE FLUID CONNECTIONS	X	X					X	X			X						
MATE & DEMATE ELECTRICAL CONNECTORS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
ACTUATE/INSTALL & REMOVE MECH. FASTENERS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X
INSTALL & REMOVE ITEM	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
TETHER & RELEASE UNSUPPORTED ITEMS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
DECONTAMINATE REMOVED HARDWARE	X	X															
SERVICE & REFUEL																	
GAUGE FLUID QUANTITIES		X															
MATE & DEMATE FLUID CONNECTIONS		X															
DISTRIBUTE FLUIDS BETWEEN TANKS		X															
VENT PRESSURE VESSELS		X															
REFURBISH PASSIVE SURFACES					X						X						
CLEAN LENS/SENSOR HEAD														X			
CALIBRATE SENSORS										X				X		X	
REFURBISH & REPAIR																	
STRAIGHTEN DEFORMED MATERIAL	X	X	X		X	X	X	X	X	X	X						X
REPAIR DAMAGED FLUID LEAKAGE AT FITTINGS	X	X					X				X						
ISOLATE/REPLACE DAMAGED TUBING		X					X				X						
REPAIR DAMAGED ELECTRICAL CONNECTORS	X	X	X		X	X	X	X	X	X	X						
REPAIR/REPLACE DAMAGED ELECTRICAL HARNESSES			X						X	X	X						
REPLACE MECHANICAL FASTENERS	X	X	X		X	X	X	X	X	X	X						X
TRIM AWAY DAMAGED MATERIAL					X												X
MEASURE LENGTH & STRAIGHTNESS																	X
SMOOTH ROUGH/JAGGED EDGES																	X
MAKE FASTENER HOLES																	X
FABRICATE REPAIR SECTIONS																	X
BOND/WELD REPAIR SECTION																	X
REFILL FLUID SYSTEM											X						

REQUIRED SATELLITE SERVICE TASK EQUIPMENT

SERVICE TASK	NO TOOLS	SUPPLIES	SHIELDS/ BAFFLES	SIMPLE HAND TOOLS	HAND HELD POWER TOOLS	FLIGHT SERVICE EQUIPMENT
	SERVICE TASK EQUIPMENT					
MATE & DEMATE ELECTRICAL CONNECTORS	X					
ACTUATE SWITCH/BREAKER	X					
VISUAL INSPECTION	X					
CLEAN LENS/SENSOR HEAD	X	X			X	
INSTALL & REMOVE ITEM	X			X		
SHIELD JAGGED/SHARP EDGES	X	X				
SHIELD PRESSURE VESSELS	X		X			
INSTALL & REMOVE THRUSTER BAFFLES	X		X			
SHIELD RADIATION SOURCES	X		X			
MATE/DEMATE FLUID CONNECTIONS	X			X		
ACTUATE/INSTALL & REMOVE MECH. FASTENERS	X			X	X	
REFURBISH PASSIVE SURFACES		X		X		
TETHER & RELEASE UNSUPPORTED ITEMS	X	X				
REMOVE ANTENNA				X	X	
TRIM AWAY DAMAGED MATERIAL				X	X	
SMOOTHE ROUGH/JAGGED EDGES				X	X	
MAKE FASTENER HOLES				X	X	
REPLACE MECHANICAL FASTENERS	X	X		X		
FABRICATE REPAIR SECTIONS		X		X	X	
BOND/WELD REPAIR SECTIONS		X			X	
STRAIGHTEN DEFORMED METAL				X	X	
MEASURE LENGTH & STRAIGHTNESS				X		
REPAIR FLUID LEAKAGE AT FITTINGS		X		X		
REPAIR DAMAGED FLUID FITTINGS/TUBING						X
REPLACE DAMAGED TUBING		X		X	X	
REPAIR DAMAGED ELECTRICAL CONNECTORS		X		X		
REPAIR DAMAGED ELECTRICAL HARNESSES		X		X		
REPLACE DAMAGED ELECTRICAL HARNESSES				X		
CHECK ELECTRICAL CONTINUITY				X		
ISOLATE FLUIDS		X				X
VENT PRESSURE VESSELS						X
CHECK FLUID LEAKAGE		X				X
CHECK ITEM PERFORMANCE/CONDITION						X
GAGE FLUID QUANTITIES						X
DECONTAMINATE REMOVED HARDWARE						X
DISTRIBUTE FLUIDS BETWEEN TANKS						X
REFILL FLUID SYSTEM		X				X
CALIBRATE SENSORS						X

EVA EQUIPMENT CONCEPTS TO SUPPORT SATELLITE OPERATIONS



ECWS for satellite operation in payload bay or on RMS:

- ECWS concept with flexible legs
- Enhanced computer capability with plug-in satellite service diagnostic and service procedures

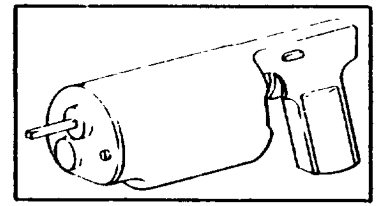
ECWS for satellite operations up to 10 km away from Orbiter

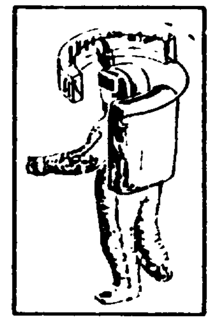
- ECWS concept with rigid leg enclosure, integral radiator and optional manipulator module
- Enhanced computer capability with rate-range-spin detection, transfer trajectory orbital mechanics calculation, remote surface temperature measurement, voice control of maneuvering unit and heads-up data display. Permits minimum energy travel to distant locations and safe approach to distant vehicles.
- Remote TV monitor, helmet mounted, with scan under IV control

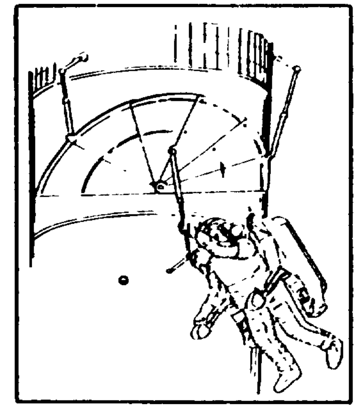
Maneuvering unit

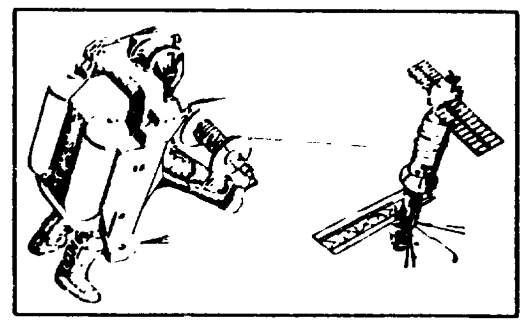
- Increased ΔV
- Voice control from ECWS
- Fully folding control arms for close access to worksite
- Coarse CG trim for variable man-payload combinations

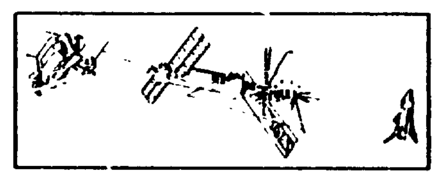
EVA EQUIPMENT CONCEPTS TO SUPPORT SATELLITE OPERATIONS (CONTINUED)











Work aids

- Portable workstand with adhesive bonding to satellite
- Hand-held power tool
- Tool caddy
- Decontamination facility — potential requirement for handling hydrazine
- Fuse bond tool

Service equipment

- Fluid system refill — fuels, pressurants and coolants
- Leak detection
- Fluid isolation
- Subsystems diagnosis and checkout

Retrieval aids

- Stabilization kit — Casting a line ensnares a satellite. Drag forces applied through a line reel and generated by the maneuvering unit remove unwanted dynamics from the satellite.
- Retrieval kit — A line guided thruster pack senses direction back to orbiter and corrects return trajectory accordingly.
- Debris retrieval — Large and small debris is retrieved and stowed in Orbiter for return to Earth

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 1, Executive Summary

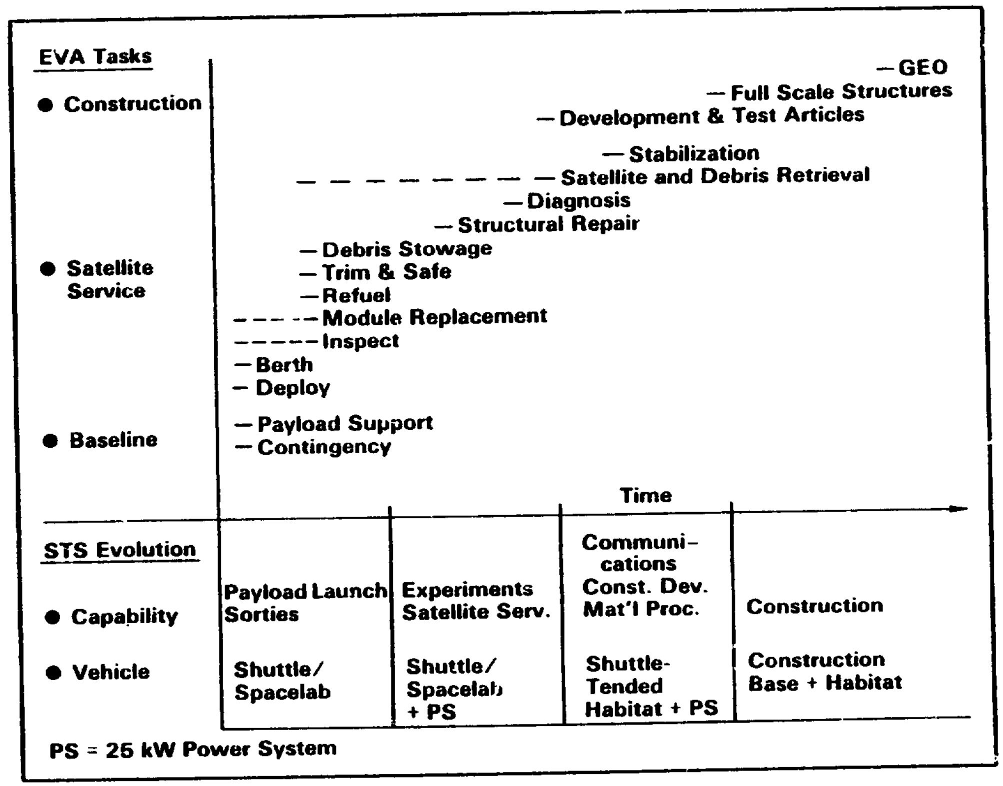
- Introduction
- ECWS Work Tasks Req'ts
- ECWS Performance Req'ts
- Concept Selection
- ECWS Preliminary Design
- Satellite Service Analysis
- New Technology Req'ts

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

ECWS PROGRAM EVOLUTION

The ECWS Study Program defined EVA equipment concepts to support satellite service and construction of large scale structures. Twenty-six of the recommended EVA equipment concepts require some level of new technology development prior to DDT&E of flight hardware. In order to identify when new technology development should be started, an overall EVA capability evolution was planned. Refer to p. 7-4. This plan matches EVA tasks with STS capability evolution, as shown in the accompanying chart. Features of the chart are as follows:

- STS capability will evolve with time. Payload launch and support capability will evolve into satellite service and construction as vehicles progress from shuttle/spacelab to manned habitats.
- EVA will be required to support STS capability at each step. Starting with baseline EVA capability of present EMU, EVA capability will evolve to support satellite service first and construction subsequently.



EVA CAPABILITY PACKAGES

ɲability packages provide a logical and manageable sequence for developing 'A capability to support satellite operation and construction. Rationale for ..e capability package sequence is as follows:

- Seven increments will develop EVA from present baseline capability to supporting operations up to 10 km distant
- Increment sequence is consistent with STS capability evolution
- Increments track increasing satellite population and serviceability
- Increments group interrelated changes together to simplify program management. Only one integration task per package
- Increments reflect technology development lead times
- EVA capability is developed first in vicinity of Orbiter. Allows accumulation of experience and confidence before committing to more distant EVA

Pkg	Increasing Service Capability	Capability Package Required		
7	More Distant EVA Capability EVA Stabilization & Retrieval Free Flying Debris Collection Construction			Pkg 6+ Stabilization Kit Retrieval Kit Debris Kit Use of Enhanced Computer Capability
6	More in EVA Capability Imaging Assistance Remote Diagnostics & Service Construction		Pkg 5+ Satellite Service MMU TV Monitor Remote Service Kit Manipulator Module Rigid Leg Enclosure	
5	Improved EMU Capability – Reduced Consummables Use Support High EVA Levels Increased Satellite Service Capability	Pkg 4+ Long Life SSA & Incremental Hazards Protection Regenerable CO_2 Removal Non Venting Heat Sink 8 Hr EVA Capability Enhanced Computer Capability Repackaged LSS		
4	• Mature Service Capability – Fluid System & Minor Electrical Repair: Electrical/Electronic Diagnosis & Checkout	Pkg 3+ Subsystems Diagnostics & Checkout Kit Leak Detection Kit Fluid System Refill Kit Fluid Isolation Kit		
3	• Structural Repair Material Cutting & Bonding Rapid Fastener Handling	Pkg 2+ Hand Held Power Tool Fuse Bond Tool		
2	• Routine Servicing Subsystem Safetying & Debris Stowage – Lens/Sensor Cleaning & Refueling Two Handed Work Capability Eliminate Prebreathe	Pkg 1+ Service Materials Supplies & Repair Parts Hand Tools Tool Caddy & Tram Line Baffles Shields & Adapters Work Platform & Adhesive Bond Gun Wide Angle Helmet & Rugged Gloves Decontamination		
1	Baseline Capability Normal & Contingency Deployment & Berthing Inspection of Orbiter & Payloads – Module Replacement – Tile Repair P/L Door Closure Rescue	Shuttle EMU MMU RMS Select Hand Tools		
		Payload Bay & RMS Envelope	Within 100m	Within 10 km

Work Distance from Orbiter or Habitat

ECWS NEW TECHNOLOGY DEVE

Year	81	82	83	84	85	

STA Capability Evolu

Spacelab sortie

25 kW power system

Satellite placement & retrieval
- RMS
- EMU
- MMU

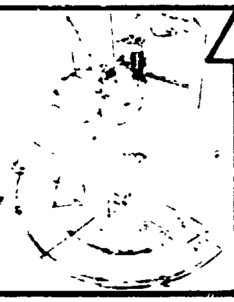
Satellite r
- En
- EV
- Ch

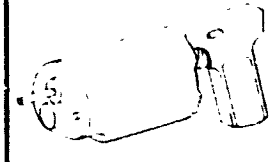
Increasing Capability

Capability Packages

1 Existing baseline

2 Helmet, gloves, workstand, adhesive bond tool, refuel decontamination, tools, no prebreathe





3 Power tool, weld/adhesive bond tool

4 Diagnosis and checkout, leak detection, fluid r

5 Soft goods, hazards protection

Enhanced computer, regenerable CO_2 non-venting heat sink, LSS packaging

6 Maneuvering unit manipulator

TV monitor

Leg can and rac

7 Use enhanced co

Key

Concept

DDT&E

Flt. hdw. mfg.

FOLDOUT FRAME

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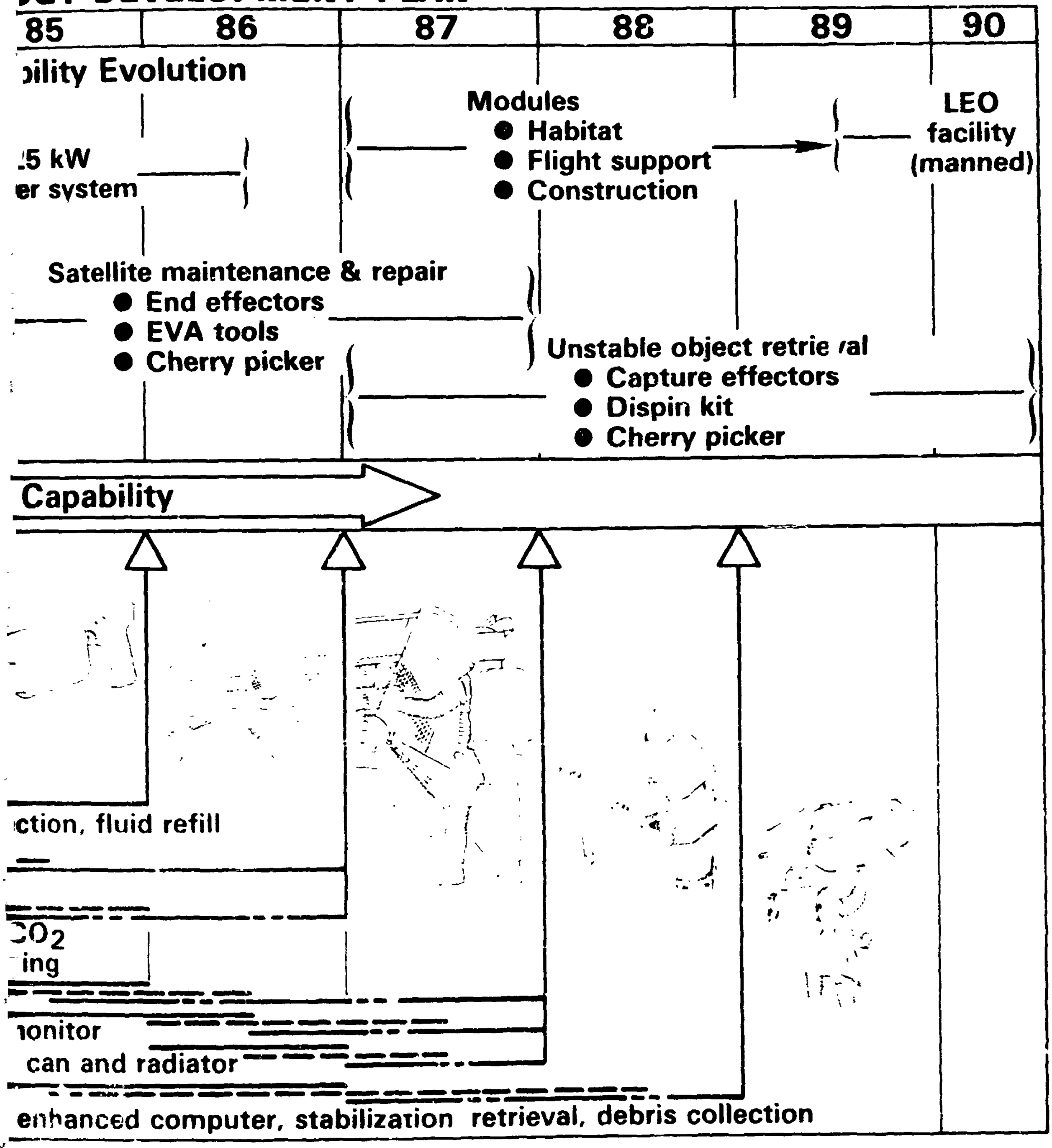
)GY DEVELOPMENT PLAN



FOLDOUT FRAME 2

SUMMARY OF EVA CAPABILITY DEVELOPMENT PROGRAM STARTS

Program Start	Package	Capability	Capability Development Required	IOC
1981	2	Routine Servicing	Helmet, Gloves, Workstand, Adhesive Bond Tool, Refuel and Decontamination Facilities. Eliminate Prebreathe	1984
1981	3	Structural Repair	Hand-Held Power Tool Weld / Adhesive Bond	1985
1983	4	Mature Service Capability	Diagnosis and Checkout Fluid Isolation Fluid System Refill	1986
1982	5	Improved EMU Capability	Long Life Softgoods Hazards Protection Enhanced Computer Capability Regenerable CO_2 Removal Non-Venting Heat Sink Repackaged LSS	1987
1983	6	Near-in EVA Capability	Hi ΔV MMU TV Monitor Manipulator Integrated Radiator / Leg Encasement	1988
1984	7	More Distant EVA Capability	Implementation of Enhanced Computer Capability, Stabilization Kit Satellite Retrieval Kit Debris Collection	1989